# Development of Satellite Based Sensor for Unambiguous Retrieval of Ionospheric Data in Conjunction with Ground Based Receivers

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## LONG-TERM GOALS

Accurate descriptions of electron density distributions in the ionosphere and the meteorological condition in the troposphere, covering most of the entire globe is needed for various operational, technical and scientific purposes. Measurements of integrated electron densities using transmissions from GPS, NNSS or other beacon satellites can be used to retrieve the height distribution of electron densities over wide regions of interest. CRS has developed the most comprehensive software for such retrieval. Extensive simulations have been performed and we have demonstrated that neither ground based receivers, nor satellite based receivers alone are capable of fully recovering the ionospheric profiles with reasonable accuracies. Satellite based receivers, in conjunction with ground based receivers, however, can provide the desired ionospheric informations, even for the bottomside lower ionosphere.

A series of beacon satellites operating at VHF frequencies are currently planned. The VHF frequencies offer superior accuracies and the satellite based receivers should contain both GPS sensors as well as VHF sensors. Results of the simulation studies have provided us with sufficient guidance to specify and design improved VHF beacons. During Phase II, we propose to design and develop prototype dual frequency GPS receiver, VHF receivers and improved VHF beacons.

The proposed combinations of sensors will also allow accurate retrieval of tropospheric parameters i.e. temperature and densities. The GPS signal at GHz frequencies will suffer the most tropospheric effects. The VHF beacon and receivers on the other hand will be able to monitor the ionospheric contributions. Improved tropospheric data will be beneficial to various operational systems and agencies.

A novel software based architecture for integrated VHF and GPS receivers operating at multiple frequencies is proposed for precise retrieval of ionospheric and tropospheric delays. The software based approach will provide improved performance, flexibility, adaptation to new applications, reduced cost and an open architecture.

## OBJECTIVES

One of the main objectives of the Phase I effort is to define the requirements for the satellite beacons. A noel 3-D ionospheric reconstruction module has been developed and this will be used for simulation. The second objective is to perform initial design of the beacons, including the choice of frequencies, desired accuracies, choice of modulation etc.

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## APPROACH

*Concept*

We proposed a small low powered satellite based GPS/VHF receiver and a dual frequency beacon. TEC data from the satellite based GPS receiver will be telemetered to the ground and this TEC data (between the satellite based GPS receiver and GPS/VHF satellites) in conjunction with the TEC data obtained from ground based receivers (using both the proposed satellite beacons and the GPS/VHF satellites) will provide a complete restoration of electron density profiles. These electron density profiles will provide superior accuracies, superior spatial and temporal resolution than what is currently available and will cover a wide geographical area. The proposed system will be inexpensive, low cost, low powered and will enhance our monitoring capabilities of the earth's ionosphere and its response towards space weather related effects.

The proposed system will provide superior information regarding:

1. Slant-path TEC from measurements of GPS/VHF satellite to the on-orbit GPS/VHF receiver.

2. TEC measurements from on-orbit satellite beacon to ground based receivers.

3. Scintillation measurements of both amplitude and carrier phase for both paths (1) and (2).

The data obtained from the on-orbit GPS/VHF receiver and the ground based receivers (receiving both on-orbit beacons and GPS/VHF satellites), will provide "complete", restoration of electron density profiles. The data can also be used for restoration of atmospheric refractive-index profiles and their derivatives.

*Ionospheric Tomography*

Use of TEC data obtained along multiple paths at different angles from satellites to receivers have been used to reconstruct the ionospheric profiles. Various numerical algorithms have been used, multiple satellites and multiple receivers at ground have been investigated and both satellite to ground as well as from satellite to satellite (using GPS-MET) data have been analyzed. CRS has developed the most comprehensive simulation and real time reconstruction techniques and has performed simulations using most of the algorithms as well as using various satellite/receiver configurations. This effort was originally started during 1994 and is being supported by NCCOSC NDRTE Center.

It is obvious that ground based tomography provides a very incomplete coverage of view angles and the tomographic reconstruction techniques provide very little information about the height variation of electron densities. Similar efforts using satellite based GPS receivers (GPS-MET, used by JPL group), also indicate poor resolution in horizontal dimension. It is apparent that improved tomographic reconstruction require the divergent rays passing through any cell (in the ionosphere). Ideal divergence is achieved when the rays intersect at angles nearing 90 degrees. This cannot be attained either through ground based or space based systems, but can be achieved when both of these systems are used together. This is what is proposed here.

Another important issue in ionosphere reconstruction is the protonospheric contribution in GPS based TEC. This cannot be resolved using the currently available systems and particularly with the

uncertainties arising through the calibration errors in GPS. Using a satellite with lower frequency beacon and with passes at lower heights, the protonospheric contribution can be resolved.

*Scintillation*

Measurement of both space to space and space to ground will be provided through the proposed system. These measurements performed at different paths and for different frequencies can be used for reconstructing the irregularity structures (as in tomography). Use of a lower frequency beacon will provide improved sensitivity and the LEO orbiting beacon will provide improved spatial and temporal coverage. The on-board GPS receiver will measure L1 and L2 intensities and dispersive phase between them at 50 to 100 samples per second. The TEC induced slow variations can be removed from the rapidly fluctuating phase scintillation using standard detrending.

While the VHF beacons can provide scintillation data, they might be saturated due to strong irregularities encountered near equator during the high solar cycle period. Use of a GPS like frequency (near 1 GHz) would provide measurable scintillation. Scintillation measurements would require design of improved receiver which should maintain lock during scintillation and would provide higher sampling rates.

*Tropospheric Data*

The technique for retrieving tropospheric data of temperature, pressure, and water vapor from GPS-MET data has been demonstrated. GPS-MET successfully demonstrated that remote sensing of the atmosphere using active radio-occultation technique using GPS is feasible, reliable, accurate and inexpensive. The proposed system will provide full capability of recovering tropospheric-data.

Both temperature and moisture contribute to the refractive index in the lower troposphere and in general it is difficult to separate the two contributions. A major source of error in these measurements came from ionospheric corrections, which can not be adequately accounted for using the GPS frequencies alone. It has been realized that for tropospheric retrieval the bending due to ionosphere also needs to be corrected for. All of these demand accurate retrieval of ionospheric profiles.

## WORK COMPLETED

Most of the Phase I work is nearing completion. A novel versatile 3-D tomographic reconstruction system has been developed. This is the only software which allows:

1. 3-D simulation using GPS and/or any other satellite.

2. 4-D reconstruction in space and time.

3. Beacons and/or receivers to be positioned anywhere. This allows simulation using satellite borne receivers.

4. Horizontal inhomogenities even when using satellite borne receivers.

5. Incorporation of novel technique to obtain independent estimate of height of the ionosphere.

6. Integration with other real time data.

These simulations have allowed us to define the requirements of improved beacons.

## RESULTS

Results of simulation has allowed us to perform preliminary design of the future beacons. A software based beacon receiver has been designed. Several of these results will be presented at the Ionospheric Effects Symposium during May 1999.

## IMPACT/APPLICATIONS

The simulation tool and the real time data assimilation system will provide valuable input for spatial and temporal extrapolation of the ionosphere. It will find numerous applications in OTH Radar, communication, EW (Signal Site Location; Coordinate Registration), Ionospheric retrieval etc. The software based receiver will provide improved performance, flexibility and will be used by GPS user community.

## TRANSITIONS

The overall objective of this SBIR is to develop a flexible receiver for intercomparison, validation, and monitoring of the ionosphere. During Phase I, we have identified scientific, technical, and operational needs. Based on these, we have concentrated on the design and development of a state-of-the-art VHF and L band receiver for deployment in a small, inexpensive satellite that can be quickly designed, constructed, and launched. We defined system requirements, performed initial system design, and demonstrated real-time analysis capabilities.

During Phase II, the objective is to perform a complete system and engineering design compatible with mission elements. The proposed receiver architecture is novel and flexible. It can be adapted to various beacons both in use and in the drawing boards.

Use of such flexible receivers will find immediate use from various agencies of DoD, including those from ONR, NRL, AF, as well as from COSMIC and other related efforts. The NPOESS program will be soliciting space based receiver development relevant to AF/NOAA requirements. Similar approaches will be used with other programs (COSMIC) or agencies.

In Airborne applications such as in Aircraft, Missile, and other similar objects, the high dynamics in conjunction with scintillation produce severe problems. The proposed approach provides a means to mitigate these detrimental effects and will extend the range of applications for GPS receivers.

Such a system will also find applications in monitoring space-weather in order to predict the problem areas from GPS application. The system will also provide an improved TEC model for estimating errors in cycle measurements etc. in presence of scintillation. Several commercial applications exist.

## RELATED PROJECTS

One of the first uses of GPS for ionospheric tomography was performed by the P.I. at the Center for Remote Sensing. The most significant related effort is being performed at the Center For Remote

Sensing under contract from NCCOSC RDTE Center, where a comprehensive software system has been developed for simulation as well as for real time specification of the ionosphere at any location.